Potassium, Magnesium, and Calcium

DEFICIENCY SYMPTOMS

of Loblolly and Virginia Pine Seedlings

by Edward I. Sucoff

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Symptoms of Sickness

A LOBLOLLY pine or Virginia pine tree that shows visible symptoms of nutrient deficiency is sick. This means that the life processes of the tree are malfunctioning and that, among other things, the growth rate is probably less than normal, and the life of the tree may be threatened. However, if the deficiency can be identified, treatment with the proper fertilizer may correct the ailment. The preliminary identification of nutrient deficiencies can often be made by visual examination of the tree, once the symptoms characteristic of each essential element are known.

Nitrogen and phosphorous deficiency symptoms on loblolly pine (*Pinus taeda* L.) and Virginia pine (*Pinus virginiana* Mill.) were recently described by Fowells and Krauss (1959), phosphorous deficiency symptoms on loblolly pine by Richards (1956), and boron deficiency symptoms on loblolly pine by Ludbrook (1940). Davis (1949) has described the effect of calcium deficiency on the morphology and anatomy of loblolly pine meristems.

It is the purpose of this report to describe the symptoms characteristic for deficiencies of potassium, magnesium, and calcium as they appear on loblolly and Virginia pines. Since deficiency symp-

[1] This paper is based in part on investigations for a Ph.D. dissertation by the author at the University of Maryland, College Park, Md.

toms may be misleading unless checked by foliar analysis, an attempt was made to note the concentrations of these elements in the needles of healthy and deficient plants. Deficiency symptoms and the associated concentrations of the elements in the needles have not been previously reported for these three elements on either loblolly or Virginia pine.

Methods

In 1957 and 1958, two crops of loblolly pine seedlings and one crop of Virginia pine seedlings were grown from seed in automatically irrigated sand cultures. The seedlings were supplied various levels of potassium, magnesium, and calcium in experiments conducted in a greenhouse of the University of Maryland at College Park, Maryland. The 1957 and 1958 experiments were not originally designed to describe deficiency symptoms; they were designed primarily to determine the growth response of seedlings at various levels of nutrition.

1957 Experiment

Loblolly and Virginia pine seeds, collected in Maryland, were sown in flats filled with acid-washed white quartz sand in February 1957. Two months later the seedlings were transplanted into 27-liter polyethylene containers filled with white quartz sand. Each container had four seedlings of one species. Using the automatic irrigation system described by Gauch and Wadleigh (1943), each container was irrigated hourly with 1.5 liters of solution drawn from its own 25-liter reservoir of nutrient solution.

The nutrient treatments were the same for both species. Six levels of potassium were used in a randomized block design, with three replications. The levels were 0.01, 0.1, 1, 4, 6, and 15 meq./l. (milliequivalents per liter) supplied as potassium chloride. The effects of three levels of magnesium and five levels of calcium were studied, using a factorial design with two replications. The magnesium levels were 0.013, 2, and 20 meq./l. supplied as magnesium sulphate; the calcium levels were 0.01, 0.1, 1, 5, and 15 meq./l. supplied as calcium chloride. All essen-

Table 1.—Initial concentration of elements in the nutrient solutions used in sand culture of loblolly pine seedlings, 1957 and 1958

(Milliequivalents per liter)

Element or ion[1]	1957		1958		
	Potassium study	Calcium X magnesium study	Potassium study	Magnesium study	Calcium study
K	0.01 to 15	3.5	0 to 0.49	3.5	3.5
Mg	2.0	0.013 to 20	2.0	0 to 2.0	2.0
Ca	5.0	0.01 to 15	1.0	1.0	0 to 0.4
Na	0	2.5	0	0	0
NH_4	2.6	2.6	0.6	0.6	0.6
NO_3	5.8	5.8	2.0	2.0	2.0
PO_4	1.8	1.8	1.0	1.0	1.0
SO_4	2.6	1.0	0.3	0.3 to 2.3	0.3
Cl	0 to 15	0.6 to 15.6	1.0 to 1.4	2.5	5.0 to 5.4

[1]The concentrations of the minor elements in 1957 were: Fe--3.0 ppm (parts per million), B--0.50 ppm, Mn--0.50 ppm, Zn--0.05 ppm, Mo--0.02 ppm, and Cu--0.01 ppm. The concentrations in 1958 were the same except for Fe, which was reduced to 2.0 ppm.

tial elements not being varied were present in the base nutrient solution (table 1). The initial pH was 5.7. During the time between solution changes the pH dropped, but was not permitted to fall below 4.0. The nutrient solutions were replaced every 2 or 3 weeks.

Biweekly measurements and observations for deficiency symptoms were made until harvest in January 1958. At that time the needles were analyzed for potassium, magnesium, and calcium.

1958 Experiment

In 1958 only loblolly pine was studied. The methods of germinating the seed and supplying the solution were the same as in 1957 except that glazed ceramic crocks were used. The 1958 experiment contained three distinct studies, each replicated five times. In one, the seedlings were grown for 9 months at five levels of potassium: 0, 0.026, 0.05, 0.15, and 0.49 meq./l. In a second, the seedlings were grown for 7½ months at five levels of magnesium: 0, 0.084, 0.17, 0.74, and 2 meq./l., after which four crocks grown with 0.084 meq./l. were maintained an additional 100 days without magnesium. In the third study, seedlings were grown at five levels of calcium: 0, 0.04, 0.08, 0.12, and

0.40 meq./l. for 7 months, after which time four crocks grown at 0 meq./l. and four crocks grown at 0.04 meq./l. were maintained an additional 55 days without calcium.

In all the experiments, the base nutrient solutions contained all the elements not being varied (table 1). Weekly observations of the development of deficiency symptoms and biweekly measurements of growth were made. At the time of harvest the needles were analyzed for potassium, magnesium, and calcium.

Potassium Deficiency

Loblolly Pine

Potassium-deficiency symptoms appeared on loblolly pine seedlings in both 1957 and 1958. The symptoms included needle discoloration and death, reduced growth, and top dieback (figs. 1 and 2). Seedlings grown at 0 meq./l. in 1958 and 0.01 meq./l. in 1957 showed severe symptoms early in life. Since these severe symptoms differed from the milder ones appearing on seedlings grown at 0.026 meq./l. in 1958, the two sets of symptoms will be described separately. Regardless of the concentration in the nutrient solution supplying the plant or the severity of the symptoms, deficiency was always associated with potassium concentrations of 0.16 to 0.26 percent dry weight in the deficient needles.

Seedlings grown on 0 meq./l. and 0.01 meq./l. potassium showed symptoms when the stem was only 2 cm. in height above the cotyledons. First the cotyledons began dying and the tips of a few older primary needles became purple or brown; the rest of the needles were grayish-green. Next the purpling or browning increased, covering the tips of all but the uppermost needles. Then, as the deficiency progressed, the uppermost needles became purple and tufted, spiralling around the terminal (fig. 3).

Height growth meanwhile was very slow: the primary needles expanded less than usual, and few fascicular needles developed. Those fascicular needles that did appear were not normal. They were less than half the normal length and soon developed brown tips. In 1957 the three needles within a fascicle spiralled, making as many as 10 twists.

Figure 1.—Healthy and potassium-deficient loblolly pine (LP) and Virginia pine (VP) seedlings grown for 11 months in sand culture, 1957. The larger seedlings of both species were supplied with 1.00 meq./l. (milliequivalents per liter) in the nutrient solution and had potassium concentrations in the needles of more than 1.00 percent dry weight. The deficient seedlings were supplied with 0.01 meq./l. and had concentrations in the needles of about 0.26 percent.

Next, the terminal stem began to die. At this stage of growth the plants were 5 to 10 cm. in height. Death at the terminal stimulated the elongation of basal shoots, but the tips of these basal shoots also died back. Despite the severe effects of deficiency, the seedlings were still alive at the end of the experiment. They were only 3 to 10 cm. in height (compared to 80 cm. for healthy plants); all of their terminals were dead, and all of their needles were brown to within 4 cm. of the stem. These symptoms agree generally with descriptions of potassium deficiency on other pine species (Hobbs 1944, Mitchell 1939, and Purnell 1958).

Less severe symptoms were shown by plants that received more potassium, and therefore exhibited deficiencies later in their devel-

Figure 2.—The roots of 1958 loblolly pine seedlings grown in sand culture for 9 months. The supplies of potassium in the nutrient solutions were, from left to right: 0.49 meq./l. (high), 0.05 meq./l. (medium), and 0 meq./l. (low).

opment. Seedlings grown with 0.026 meq./l. potassium in 1958 were 15 to 70 cm. tall before a lack of potassium caused visible deficiency symptoms. Growth and needle elongation were retarded but never stopped. Complex needle discolorations appeared. The needles looked as though they had been painted in water colors with shades of purples, browns, yellows, and greens. Three patterns of color distribution appeared in the needles repeatedly:

Pattern I. The middle third of the needle and a length of 1 cm. at the tip were brown; the rest of the needle was green.

Pattern II. Bands of chocolate-brown and purple ringed the otherwise faded-green needle. The bands occurred mostly in the tip half of the needle.

Pattern III. The basal portion of the needle was green. A middle band of yellow separated the green from a terminal portion, which was a mosaic of browns, greens, purples, and yellows.

Considering the entire plant, the development of deficiency symptoms followed these steps:

1. Needles on the central portion of the plant, usually the third or fourth internode, became faded green.

2. Small necrotic spots developed on these needles.

3. Spots coalesced and Patterns I, II, and III developed.

4. Large portions of the needles turned brown, and needles further down and up the plant became chlorotic.

5. Needles on the central part of the plant browned completely, and browning began on older needles.

This stepwise development of the deficiency is in part illustrated

Figure 3.—The terminal of a potassium-deficient loblolly pine seedling. The shoot curvature is typical of severe deficiency prior to dieback. The short needles twisted around the terminal are purple. The longer fascicular needles are brown to within 5 cm. of the stem.

by seedlings described in table 2. The seedlings are arrayed from top to bottom in progressively more severe stages of potassium deficiency.

Virginia Pine

Severe potassium deficiency appeared on Virginia pine seedlings grown at 0.01 meq./l. potassium. The symptoms were generally similar to those for loblolly pines grown at the same concentration (fig. 1). However, the terminals of Virginia pine were more sensitive to a lack of potassium. Sometimes browning and

Table 2.—Appearance of loblolly pine seedlings suffering from potassium deficiency

Height: At harvest	Height: When deficiency first observed	Internode	Color of fascicular needles
Cm.	Cm.		
70	55	Top	Green.
		2nd	Green.
		3rd	Some purple spots.
		4th	Tip 2/3 of needle brown or Pattern III.
		5th	Tip 1/5 of needle brown or Pattern II and III.
		6th	Tip cm. of needle brown.
70	70	Top	Green.
		2nd	Green.
		3rd	Tip 1/3 of needle brown and Patterns I and II.
		4th	Tip 1/2 of needle brown or Pattern III.
		5th	Tip 1/4-2/3 of some needles brown.
		6th	Tip cm. of needle brown.
		7th	Tip 3 cm. of needle brown.
30	25	Top	Dark green abnormally small.
		2nd	Tip 1/3 of needle brown or Patterns I and II.
		3rd	Tip 1/2 of needle brown or Pattern III.
		4th	Tip 1/2 of needle brown or Pattern III.
		5th	Tip 1/5 of needle brown or Pattern I.
12	2	Top	Green.
		2nd	Chlorotic.
		3rd	Tip chlorotic.
		4th	Chlorotic, tip 1/4-2/3 of needle brown.
		5th	Chlorotic, tip 1/4-2/3 of needle brown.

purpling of the terminal needles was the first symptom, and top dieback occurred more rapidly than with loblolly pine. The potassium concentration in the needles of deficient plants was about 0.26 percent dry weight.

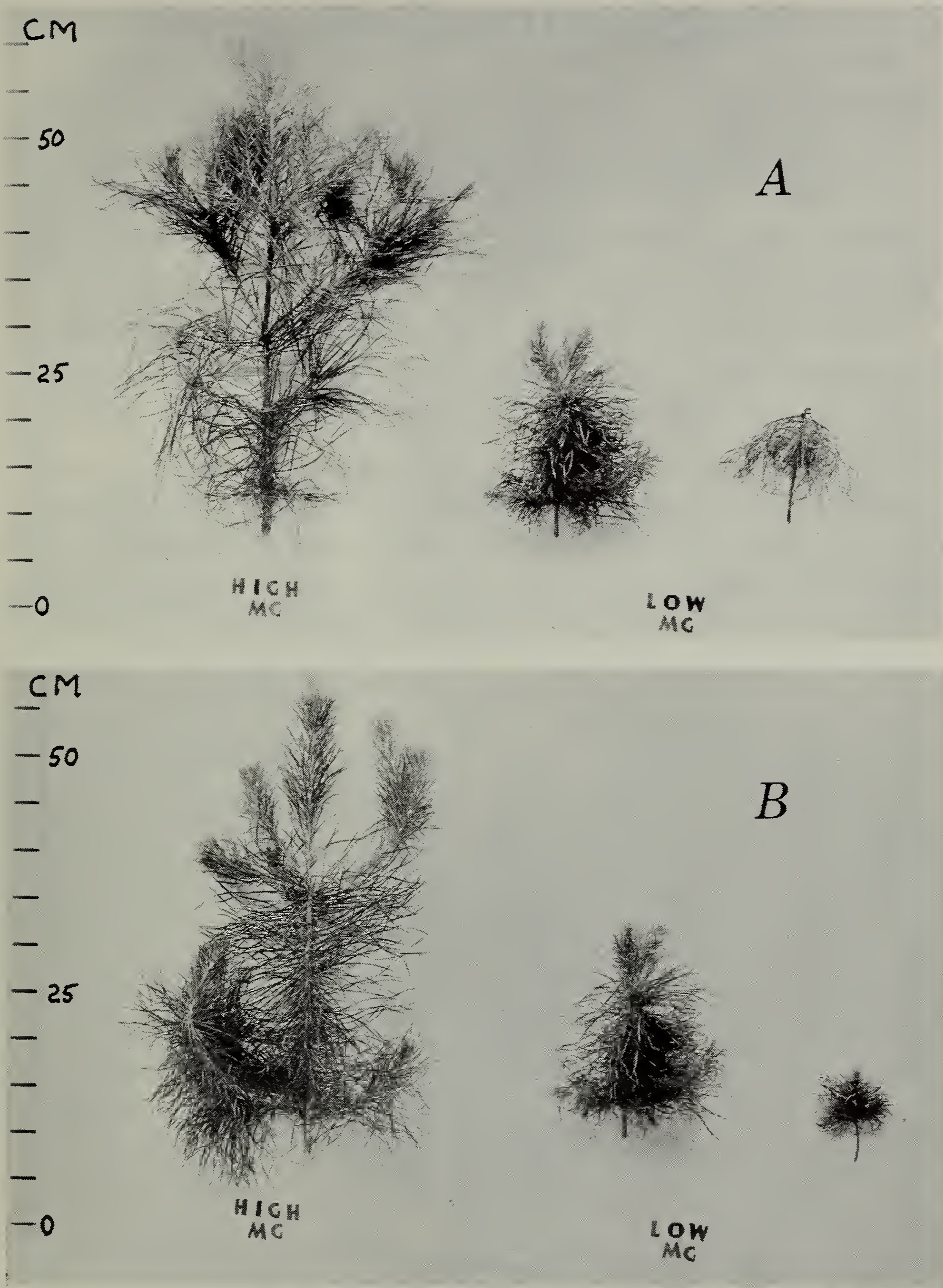

Figure 4.—One healthy and two magnesium-deficient seedlings of (A) loblolly pine and (B) Virginia pine. The healthy seedlings were supplied with 2 meq./l., and the deficient seedlings with 0.013 meq./l. The concentration of magnesium in the needles of the healthy plant was about 0.25 percent dry weight; the concentrations in the deficient plants, about 0.05 to 0.08 percent. All the needles of the smallest seedling are yellowed and browned. The yellowed and browned needles on the intermediate seedling are located only in the center of the plant.

Magnesium Deficiency

Loblolly Pine

The loblolly pine seedlings grown with 0 meq./l. in 1958 and 0.013 meq./l. in 1957 showed clear and striking magnesium-deficiency symptoms. Reduced growth, yellow and brown needles, and dieback were found on these seedlings (figs. 4A and 5).

The most severely affected seedlings were those grown without any magnesium. The magnesium concentration in the needles of these plants ranged from 0.006 to 0.02 percent dry weight. Following a series of hot, clear days the tips of all primary needles turned a pure yellow. The seedlings were only 2 to 3 cm. tall at this time. The yellow moved rapidly down the tip half of the needle. Browning followed progressively, but the basal half of the needles remained green. Concurrent with the browning of the

Figure 5.—Close-up of the magnesium-deficient loblolly pine seedling shown in figure 4A. The top has died back. The long drooping fascicular needles are yellow and brown and have the texture of fine, dry grass. Only the base of any needle is green.

primary needles was the development of the fascicular needles. All of these needles, when they were about 7 to 12 cm. long, turned yellow-green or pale yellow at their tips. Again, browning from the tip soon followed the chlorosis, so that each fascicular needle contained three zones—a brown tip, a yellow middle, and a dark green base. After a while, the entire needle turned brown except for the basal 1 or 2 cm.; this portion remained dark green. The needles felt like fine dry grass. Similar observations of progressive yellowing and browning have been made on other pines deficient in magnesium (Hobbs 1944, Stone 1953, and Lafond 1958).

Lateral branches did not develop on these severely deficient seedlings except just above the cotyledons. The terminals, however, kept elongating till the plants were 5 to 15 cm. tall. Top dieback began at this stage, and in time many seedlings browned completely. The root systems of these seedlings, excavated at the death of the top, were small, showed little branching, and had many dead parts. Purnell (1958) made similar observations of the roots of magnesium-deficient Monterey pine.

The severe deficiency symptoms described above for plants supplied no magnesium were sometimes, but not usually, found on the seedlings grown in the 1957 experiment on 0.013 meq. magnesium per liter. Needles of deficient plants had magnesium concentrations of 0.05 to 0.08 percent dry weight. These seedlings developed deficiency more slowly, often reaching 25 cm. before the needles started to change color. It was always the older fascicular needles that changed color first; the younger needles remained green. When the deficiency was less pronounced, only the needles in the third and fourth internodes from the top turned yellow and brown. If the deficiency was greater, all the needles except the youngest were affected. The observation that the young needles did not yellow is of special interest since it differs from the reports of other workers (Stone 1953 and Lafond 1958) and the results of the 1958 experiment. The reasons for the different symptoms are not understood.

In the 1958 experiment, magnesium deficiency was produced on seedlings 50 to 120 cm. tall by withholding magnesium for

100 days from plants that had been grown for 7 months previously with 0.084 meq./l. magnesium. Yellowing in these seedlings appeared exclusively on the youngest needles of the terminal and top three laterals. These needles, after reaching one-quarter to two-thirds their normal, mature size, turned yellow at their tips. The yellowing progressed quickly inward to cover one-third to one-half the needle. The yellow color, at first pale, soon intensified. Browning followed without further yellowing of the base of the needle. The needle concentration of magnesium in these seedlings was about 0.03 percent dry weight.

Virginia Pine

Virginia pine grown at 0.013 meq./l. magnesium showed the same magnesium-deficiency symptoms as loblolly pines grown at that concentration (fig. 4B). The yellowing on the Virginia pine was even more striking. The magnesium concentrations in the needles of the deficient seedlings were 0.07-0.08 percent.

Calcium Deficiency

Loblolly Pine

Loblolly pine seedlings growing in a solution to which no calcium was added (1958 experiments) showed calcium-deficiency symptoms. The symptoms occurred 7 to 9 months from seed on plants 33 to 90 cm. tall. The deficiency resulted in resin exudation from, and death of, the terminal bud and buds on the branches. It also resulted in discoloration of the needles, changes in morphology, and retarded growth.

The first symptom to appear—and the most striking—was resin exudation from the buds, first on the branches and then on the terminal leader (fig. 6). Exudation from the terminal has been reported for calcium deficiency on Monterey pine by Purnell (1958), for phosphorous deficiency on loblolly and slash pine by Richards (1956), and for boron deficiency on loblolly and Monterey pine by Ludbrook (1940). A drop of resin appeared on the tip of the bud before, or just after, bud breaking. As this drop enlarged, new drops appeared. The resin glued the undevel-

oped needles together, as later cross sections through the bud showed. Smaller buds on branches did not exude resin, but became dark and dry. This darkening and drying was observed on almost all buds of calcium-deficient loblolly pine (Davis, 1949) and Monterey pine seedlings (Purnell, 1958).

Resin exudation usually signified death of the bud. Death of a bud on the lateral branches was followed by a dying back of the entire shoot. Purnell (1958) also observed this. The dead stem appeared bluish-black in color. However, death of the main

Figure 6.—Resin exuding from buds of terminal cluster of a calcium-deficient loblolly pine. The resin has already gummed up several buds, and beads are now appearing on the most recently elongated shoot.

bud of the terminal shoot was usually followed by elongation of the other buds of the cluster. After elongating a few centimeters, these in turn began to exude resin, and then died. Interfascicular buds then elongated, but these too exuded resin and died. The three needles around each interfascicular bud were splayed at their bases up to 5 times normal width. These multi-leadered calcium-deficient seedlings looked from a distance like plants attacked by tip moth. Occasionally a bud with beads of resin recovered and resumed normal growth. In such cases the needle tips remained glued together for a time. When they finally did pull apart, the tips were dead and curled. The elongating stem from a recovered bud showed curvature resulting from damage while in the bud.

Needle discolorations occurred on loblolly seedlings grown without calcium, but were less than startling. The discolorations, such as they were, usually did not develop until after bud damage appeared. They were associated with calcium concentrations in the needles of less than 0.033 percent dry weight. Three types of needle symptoms were apparent. The first two were found on needles near the shoot tips, almost always in association with affected buds; these needles developed during a period of calcium stress. The third type occurred on needles that reached maturity before the onset of deficiency.

In the first type, the part of the needle affected initially was 5 to 10 mm. from the tip. This area became chlorotic and the cusp became bright yellow. Sometimes the chlorosis progressed no further. Instead, the basal half of the needle became indistinctly but profusely banded and spotted with yellow-green. In the midst of the chlorotic areas, red-brown spots and bands appeared. Then the chlorosis advanced to cover the terminal 4 to 5 cm. of the needle. The chlorotic color was not homogeneous as in magnesium deficiency; instead it was a subtle mottling of yellow-green, olive green, and light green.

In the second type the first symptoms were small blotches of yellow-green appearing within 10 mm. of the needle tip but not at the very tip. A larger 1 to 5 mm. yellow spot then developed from these blotches. This spot sometimes became translucent and the tissue around it browned. When the spot did not become

translucent, it reddened. The reddish color soon became a deep red-brown or black-brown. The rest of the needle was normal or showed an exceptionally dark green color and the abnormal morphology described below.

In the third type, mature green needles became profusely banded and spotted with a light green color. Similar spots and bands, but in far fewer numbers, appeared on very old needles in healthy plants.

Calcium deficiency also changed the morphology of the seedlings. Shoots developing in association with damaged buds had only one- to three-fourths as many needles as normal shoots, and these needles were shorter, wider, and thicker. They were one-third to three-fourths their normal length, two to four times their normal width, and two to three times their normal thickness (fig. 7). On calcium-deficient plants young needles exaggerated some of the characteristics of very old needles; they were tough, leather-like, less flexible, and deep green. Toward the base, these abnormal needles were very wavy. Needle discolorations did not always accompany these malformations. The root tips showed no gross abnormalities although an unusually high number were dead. Davis (1949) observed that the root tips of calcium-deficient loblolly pine seedlings were blunt, rounded, and covered with a layer of dead, partially disintegrated cells.

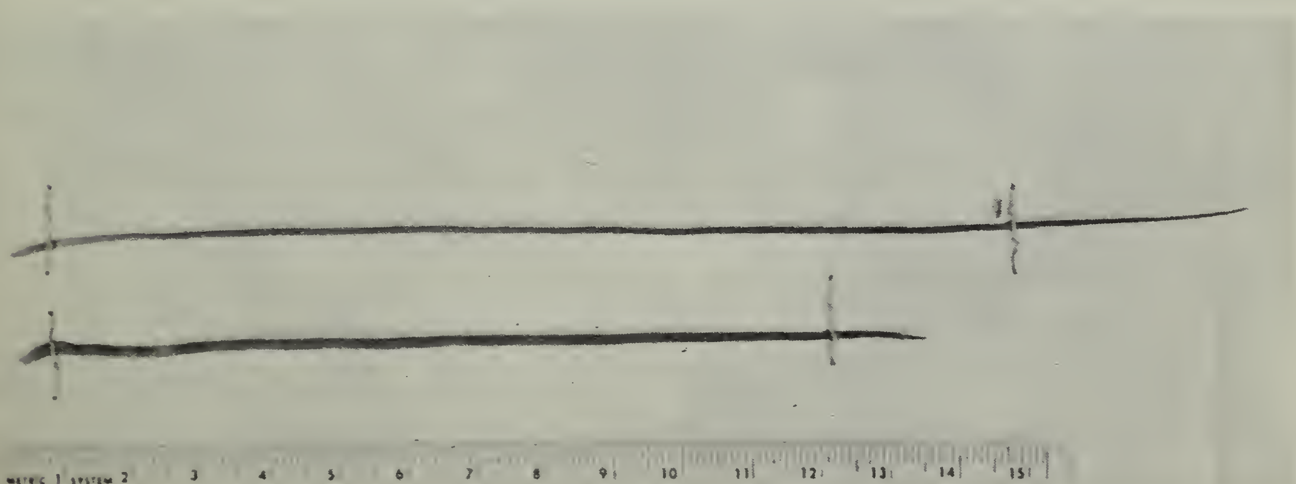

Figure 7.—A comparison between a normal loblolly pine needle *(top)* and a needle showing calcium-deficiency symptoms *(below)*. The deficient needle is shorter and wider and has a thick wavy base.

The height growth of the seedlings showing calcium-deficiency symptoms was irregularly retarded; whenever the terminal bud exuded resin, height growth stopped.

Virginia Pine

No calcium-deficiency symptoms were produced on Virginia pine. This species was studied only in the 1957 experiment, and there the lowest concentration of calcium was 0.2 ppm. plus unknown contamination. This level of supply was apparently sufficient to meet the requirements of the seedlings.

A Note of Caution

On the basis of this experiment, one might think that it is possible to make easy identification of the deficiency symptoms for the three elements: potassium, magnesium, and calcium. Purple needles would indicate potassium deficiency, yellow needles magnesium deficiency, and resin exudation calcium deficiency. However, several factors make such identification somewhat more difficult: (1) loblolly and Virginia pines may show deficiency symptoms for at least nine other elements, and it is not likely that they will all have clearcut distinguishing characteristics. In fact, as noted before, both boron and phosphorous deficiencies have been reported to result in resin exudation, which in this experiment was attributed to calcium deficiency; (2) apparently, deficiency symptoms are not always the same—as indicated by the different symptoms produced in 1957 and 1958 by magnesium deficiency; (3) multiple deficiences result in mixed symptoms; (4) widespread and intensive insect or fungus damage may cause the appearance of similar symptoms.

For these reasons, visual symptoms alone should not be completely trusted in determining the cause of deficiency. However, visual symptoms checked by foliar analysis should provide for rapid and accurate diagnosis of nutritional diseases.

Summary

Potassium-, magnesium-, and calcium-deficiency symptoms were produced on loblolly pine, and potassium- and magnesium-deficiency symptoms on Virginia pine by growing the seedlings in automatically irrigated sand cultures with limited supplies of the elements.

The potassium-deficiency symptoms were needle discoloration and death, reduced growth, and in severe cases top dieback. These symptoms were associated with potassium concentrations in the needles of the affected seedlings of 0.16 to 0.26 percent dry weight. When the deficiency was severe in 2-cm. tall seedlings, the needles purpled and browned from their tips, few fascicular needles developed, and eventually top dieback occurred. Just prior to top dieback the uppermost needles became purple and tufted, spiralling around the terminal. When the seedlings were 15-70 cm. tall before potassium deficiency occurred, the needles in the third and fourth internodes from the top first became chlorotic, then became discolored with browns, purples, and yellows—and finally died. The top two internodes developed no symptoms.

Magnesium deficiency was characterized by the yellowing of the needles, reduced growth, and finally—in severe cases—top dieback. The yellowing always began at the tip of the needles. In one experiment the older needles were affected first, in another experiment only the youngest needles turned yellow. The magnesium concentration in the needles of deficient plants was 0.006 to 0.08 percent dry weight.

Calcium deficiency, observed only on loblolly pine, resulted in resin exudation from, and later death of, the buds. It also caused a slight yellow-green mottling of the needles, chiefly at the top of the plant. On calcium-deficient plants there were fewer needles, and these were thicker, wider, and shorter than normal. The calcium concentrations in the young deficient needles were below 0.033 percent dry weight.

Deficiency symptoms when used in conjunction with foliar analysis should permit the rapid and accurate diagnosis of nutritional diseases.

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